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Simulation and practical analysis of size miniaturized multiband pentagon, L-shape microstrip slot antenna

Ambresh PA[a]* & Sujata A A[b]

[a]Department of Electronics, Mangalore University, Mangalore 574 199, India
[b]Godutai Engineering College for Women, Gulbarga 585 103, India

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This paper describes the design, simulation and experimental testing of multiband pentagon and L shape slot antenna (MPLSSA) operating for multiband frequency ranging from 2.0 GHz to 10 GHz. Significant emphasis are placed on the designing of microstrip slot and practical antenna results are carried out on Agilent Technologies E8363B Network Analyzer. The design considerations are given for microstrip feed rectangular microstrip antenna operating at a frequency of 3.5 GHz. The microstrip slot is designed on the glass epoxy substrate having dielectric constant 4.4 and is simulated using Mentor Graphics IE3D simulation software. It is compact antenna and suitable for the IEEE 802.11b, RADAR applications. Experimental and Simulation results of Return losses (RL), bandwidths, radiation patterns are presented and discussed.

Keywords: Pentagon, Slot, Wireless, Radars, Satellite, Bandwidth, Photolithography

1 Introduction

A basic communication system may consist of transmitter, receiver and medium. Medium is used to transfer the messages from transmitter to receiver and may be guided (wired) or unguided (wireless). Antenna is a vital part of the communication system and a wireless communication without proper antenna setup is unimaginable. It helps not only to transmit the messages (or data streams) but to receive them also. Mismanagement in case of transmission and reception of the messages may result in a total breakdown of the system. Thus, a proper antenna design is a vital issue which should be kept in mind while designing a communication system. So, antenna is vital part of the communication system and plays significantly paramount part in the wireless communication system. With the advent of the wireless technology, the compact size, better performance (in terms of coverage, capacity and transmission quality) and low cost antenna are huge demand in market. An antenna is a metallic device which can act as transmitter and receiver. According to Webster's dictionary, ‘‘An antenna is a metallic device (may be wire or rod) for transmitting or receiving radio waves.” IEEE standards defines antenna as a means for transmitting or receiving unguided waves[1].

The development in wireless communication technology, the need for low weight and small size antennas has become a mandatory need in the present day and future wireless world. The most popular antenna in this category is microstrip patch antenna. The microstrip patch antenna is a type of radio antenna with a low profile that can be mounted on a flat surface[1, 2, 3]. This antenna consists of a flat rectangular sheet or "patch" of metal, mounted over a larger sheet of metal called as ground plane. The assembly is usually contained inside a plastic radome, which protects the antenna structure from damage. These antennas have several advantages over other antennas such as low profile, low weight, relatively low manufacturing cost, simple fabrication process, polarization diversity and can be easily modified and customized[1, 7, 10]. One of the disadvantages of microstrip patch antenna is low bandwidth and low gain. There are various methods adopted to increase the bandwidth of microstrip antenna such as increase the substrate thickness, use of a low dielectric substrate, use of various feeding techniques and impedance matching, use of slot antenna geometry and multiple resonators[8]. But the bandwidth and size of the antenna[9] is a mutually conflicting property that is improvement of one deteriorates the characteristics of others. Microstrip printed slotted patch antennas have been extensively studied in recent years[5]. To enhance the bandwidth and size miniaturization performance parameter of antenna using slot loading technique is used[6, 12-15]. However, we have obtained a

*Corresponding author (E-mail: ambreshpa@gmail.com)

multiband with good radiation characteristics. This paper considers design of multiband pentagon and L shape slot antenna (MPLSSA) is presented which gives a multi-bandwidth characteristics.

2 Practical Design of Multiband Pentagon and L shape Slot Antenna

The design and the AutoCAD sketch of the RMA is represented in Fig. 1. It consists of a rectangular patch with dimensions *(L × W)*. The front side of the dielectric material is rectangular patch with ground plane on the back side of substrate having constant thickness. Microstrip patch is considered as a parallel combination of capacitance (C1), inductance (L1) and resistance (R1) as shown in Fig. 1. The fabrications of designed antennas are etched on widely available epoxy dielectric substrate with thickness (h) of 0.16cm and dielectric permittivity (εr) of 4.4 which is fabricated using photolithography process. A 50 Ω SMA connector is connected to the microstrip feed line for excitation of the patch. Strip line feed technique is used as the feed excitation for the patch antenna which is connected to 50 Ω SMA connector. Improved accuracy in the design is obtained when the proposed antennas are sketched using commercially available AutoCAD 2013 software. Initial design step is to choose dielectric substrate of appropriate thickness and the frequency of operation. The conventional rectangular microstrip antenna (RMA) is designed for the resonant frequency (f_r) of 3.5 GHz using the basic equations available in literature[2, 5]. The geometry of this antenna is as shown in Fig. 1. The antennas are designed by using the following equations[2](1-4). The patch width W shown in Fig. 1 is given by:

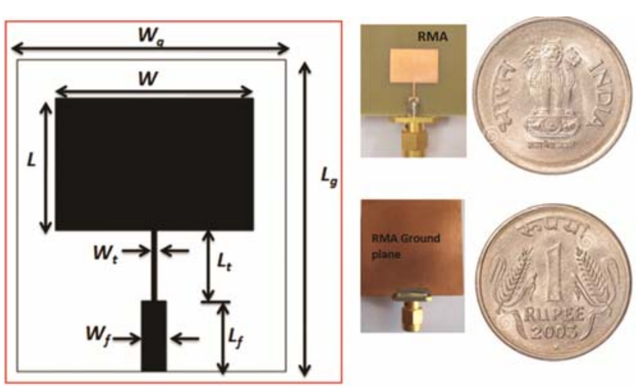

Fig. 1 — Top view geometry of conventional RMA and fabricated RMA.

$$W = \frac{c}{2f_r}\sqrt{\left(\frac{\varepsilon r+1}{2}\right)} \qquad \text{... (1)}$$

The length of patch L is given by,

$$L = \frac{c}{2 fr\sqrt{\varepsilon r}} - 2\Delta l \qquad \text{... (2)}$$

Where, effective length

$$\Delta l = 0.412h \frac{(\varepsilon e + 0.3) + \left(\frac{w}{h} + 0.264\right)}{(\varepsilon e + 0.258)\left(\frac{w}{h} + 0.8\right)} \qquad \text{... (3)}$$

$$\varepsilon_e = \left(\frac{\varepsilon_r + 1}{2}\right) + \left(\frac{\varepsilon_r - 1}{2}\right)\sqrt{1 + \frac{12h}{w}} \qquad \text{... (4)}$$

and *h* is the substrate material of thickness

The patch is fabricated on a low cost glass epoxy substrate material of thickness h = 1.66 mm and permittivity ε_r = 4.4. In order to get better accuracy, both the antennas are presketched using computer software AutoCAD-2013 and are fabricated using photolithography process practically. The length and width (*L x W*) of the patch is (19.96 *x* 26.08 mm). The length and width of quarterwave transformer (L_t x W_t) is (10.18 x 0.66 mm). The length and width of microstrip feedline (L_f x W_f) is (10.19 x 3.35 mm) which is as shown in Fig.1.

Later, the pentagon shape slot with two L shape slots are etched on the patch plane of conventional RMA as shown in Fig. 2. This antenna is named as multiband pentagon and L shape slot antenna (MPLSSA). The dimensions of the slots are taken in terms of λ_0, where λ_0 is the free space wavelength corresponding to the designed frequency of conventional RMA i.e. 3.5 GHz. The side length of pentagon shape slot (*A*) is 8.12 mm and the slot vertical length (*B* & *C*), slot horizontal width (*D* & *E*)

1 Top view geometry of conventional RMA

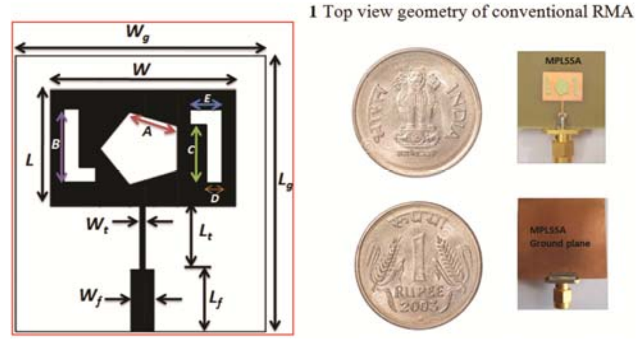

Fig. 2 — Geometry of MPLSSA and fabricated MPLSSA.

of L shape slot are (*B=15.04 mm & C=9.03 mm*) and (*D=2.34 mm & C=5.67 mm*) keeping the patch length, patch width, feed line length and width, quaterwave transformer length and width unchanged as compared to the RMA. The dimensions are also indicated in the Table 1. The main advantage of the designed antenna is its simple design having multiple resonance behavior due to slots arms etched on the patch suitable for communication applications.

3 Simulation and Practical Results of RMA and MPLSSA

The simulation and practical measurement of return loss and other antenna parameters of the designed RMA and MPLSSA were verified. Designed antennas are connected to the network analyzer through coaxial cable of microstripline feed. For the proposed antennas, the impedance bandwidth over return loss less than −10 dB was measured by Agilent Technologies E8363B Network Analyzer operated in the frequency range of 10 MHz to 40 GHz.

The variation of return loss verses frequency of RMA is as shown in Fig. 3. From the figure it is clear that, practically the antenna resonates at fr_1 = 3 GHz (Simulated resonant frequency = 3.1 GHz) of frequency which is very much close to the designed frequency of 3.5 GHz and hence validates the design. From this graph, the experimental impedance bandwidth was calculated using the formula[4]. The bandwidth of conventional RMA is found to be BW_1 = 2.06 % (practical) and 1.99 % (simulated).

Figure 4 shows the variation of return loss versus frequency of MPLSSA. From this figure it is clear that, the antenna resonates at five different bands of frequencies f_1= 2.12 GHz, f_2 = 2.5 GHz, f_3 = 3.5 GHz, f_4 = 7.6 GHz and f_5 = 9.3 GHz with their respective bandwidths (BW) are BW_1= 2.93% (2.02-2.10 GHz), BW_2 = 2.65% (2.25-2.38 GHz), BW_3= 3.36% (3.49-3.61 GHz), BW_4 = 10.19% (7.29-7.98 GHz) and BW_5 = 12.45% (8.59-9.69 GHz) respectively.

The first band BW_1 is due to the fundamental resonance of the patch. The bandwidths BW_2, BW_3, BW_4 and BW_5 are due to the insertion of equal arm lengths of L shape slot on the radiating patch as they resonate independently and act as resonant structure. The simulated result of MPLSSA is also shown in Fig. 4 which is close agreement for frequencies from f_1 to f_5 with experimental results. Since, the practical designed antenna (MPLSSA resonant frequency) resonates at lower frequency compared to design frequency of conventional RMA as in Fig. 4 it is clear

Table 1 — Parameters of the design antenna

Parameters of the design antenna	Dimensions (mm)
Length of the patch (*L*)	19.96
Width of the patch *(W*)	26.08
Substrate material thickness *(h)*	1.66
Permittivity (ε_r)	4.4
Length of quarterwave transformer (L_t)	10.18 mm
Width of quarterwave transformer (W_t)	0.66 mm
Length of feedline (L_f)	10.19 mm
Width of feedline (W_f)	3.35 mm
Side length of pentagon shape slot (*A*)	8.20 mm
Slot vertical length (*B & C)* of L slot	B=17.11 mm & C=9.35 mm
Inverted slot (Γ) horizontal width (*D & E*) of L slot	D=3.45 mm & E=6.7 mm

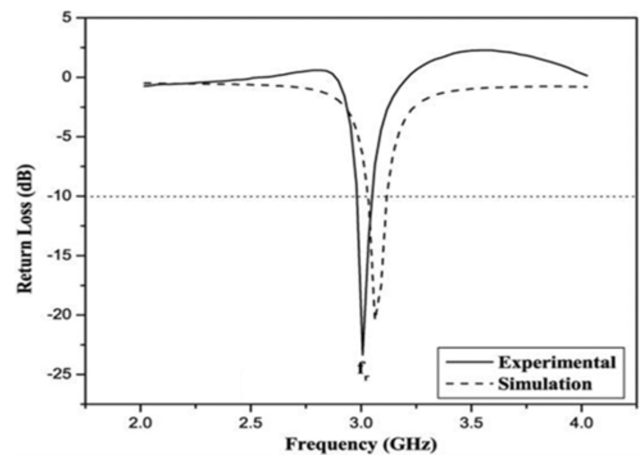

Fig. 3 — Return loss versus frequency characteristics of conventional RMA.

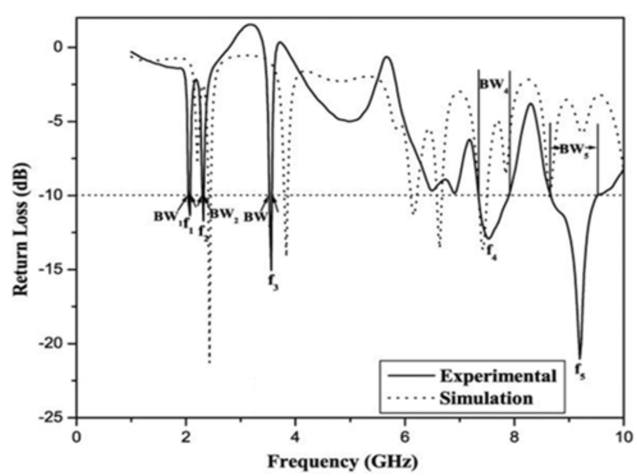

Fig. 4 — Return loss versus frequency characteristics of MPLSSA.

that the MLPSSA gives virtual size miniaturization of 47.2 %. The slight variation in experimental and simulation results in Fig. 4 is due to the effect of soldering the SMA connector to the patch or due to fabrication tolerance also the shift in frequency

Table 2 — Antenna results comparison (RMA and MPLSSA)

osed antenna/ parameters	RMA		MPLSSA	
	Experimental	Simulation	Experimental	Simulation
Resonant Frequency	f_r=3 GHz	f_r=3.1GHz	f_1= 2.12 GHz, f_2 = 2.5 GHz, f_3 = 3.5 GHz, f_4 = 7.6 GHz f_5 = 9.3 GHz	f_1= 2.3GHz, f_2 = 3.8 GHz, f_3 = 6.1 GHz, f_4 = 6.8 GHz f_5 = 7.5 GHz
Bandwidth	2.06 %	1.99 %	BW_1= 2.93% BW_2= 2.65% BW_3= 3.36% BW_4= 10.19% BW_5= 12.45%	BW_1= 2.73% BW_2= 2.51% BW_3= 4.36% BW_4= 6.19% BW_5= 8.45%
Return loss (RL)	-24dB	-20dB	-11dB -12dB -15.2dB 13.2dB -22dB	-22.5dB -14dB -11dB -13.5dB 13.7dB
Radiation pattern	Broadsided pattern		Broadsided pattern	
Virtual size reduction	22%		47.2%	

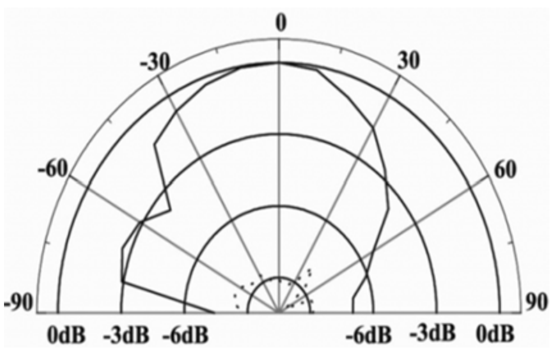

Fig. 5 — Measured radiation characteristics of RMA at 3 GHz.

compared with experimentally measured & simulated result is due to the variation of temperature dependent dielectric permittivity of substrate material and effect of 50 Ω co-axial feed. Also this, frequency shift when compared with measured result is due to the variation of temperature dependent dielectric permittivity of substrate material and effect of 50 Ω co-axial feed[11]. It is also evident from Fig. 4 that, since the simulation is performed by declaring the parameters in ideal conditions in the software and hence simulated result varies marginally to the practical results. The results of the variation of return loss of RMA and MPLSSA are given in Table 2.

For the measurement of radiation pattern, the antenna under test (AUT) i.e., the proposed antennas and standard pyramidal horn antenna are kept in far field region. The AUT, which is the receiving antenna, is kept in phase with respective transmitting pyramidal horn antenna. The power received by AUT is measured from -0^0 to $+360^0$ with the steps of 10^0.

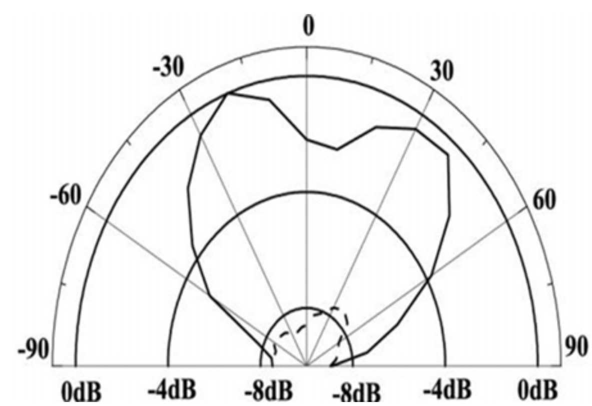

Fig. 6 — Measured radiation characteristics of MPLSSA at 2.5 GHz.

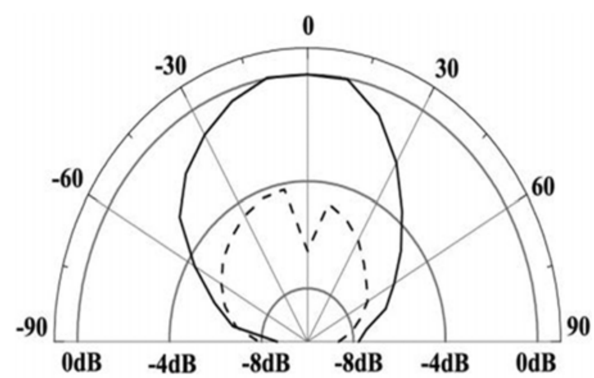

Fig. 7 — Measured radiation characteristics of MPLSSA at 3.5 GHz.

The typical far field co-polar and cross-polar radiating patterns of MPLSSA measured in their operating bands are as shown in Figs 5, 6 and 7, respectively. From these figures, it can be observed that, the patterns are broadsided and linearly polarized.

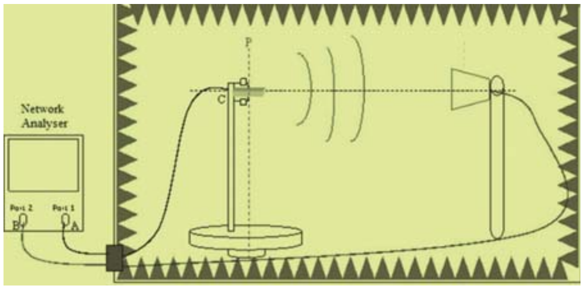

Fig. 8 — Radiation pattern measurement setup with antenna under test.

The setup for measurement of radiation pattern having antenna under test is as shown in Fig. 8.

4 Conclusions

This paper presents design, simulation and practical study on microstrip slot antenna. Designed antenna operates at multiband frequencies suitable for various multiband wireless applications, Wimax, SAR, fixed satellite services application, RADAR applications and indoor wireless applications. The proposed antenna has also achieved virtual size miniaturization of 47.2 %. The improvement in bandwidth is mainly due to the addition of slots on the patch plane.

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